

# Methodology for locating defects within hardwood logs and determining their impact on lumber-value yield

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## Abstract

A precise research methodology is described by which internal log-defect locations may help select hardwood log orientation and sawing procedure to improve lumber value. Procedures for data collection, data handling, simulated sawing, and data analysis are described. A single test log verified the methodology. Results from this log showed significant differences in lumber-value yield due to circumferential log orientation and sawing method.

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Recent advances in scanning technology make possible the scanning of logs for interior defects (1,7,35,49). However, high speed production log-scanners have not yet been developed. A probable reason is that potential lumber-value improvements resulting from detecting internal defects are not known. This paper describes a precise research methodology by which internal log-defect locations may help select log orientation and sawing procedure to improve lumber-value yield. The methodology was verified by collecting data from a test log and by performing sawing simulation procedures.

## Background

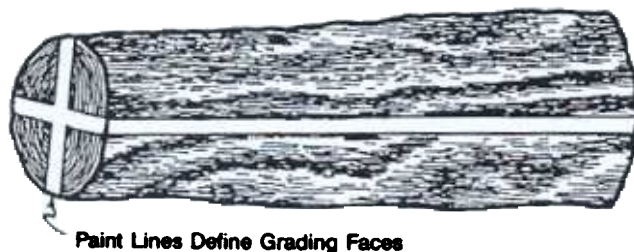
Current processes of converting hardwood logs into lumber have limited effectiveness because of a lack of knowledge about interior defects or about the potential grade and yield of lumber. The sawyer uses exterior defects on log surfaces as initial indicators of the possible number and location of internal defects. As the log is sawn and defects are exposed on each sawn face, the sawyer gains additional information to help obtain maximum lumber-grade yield. By the time a sawn face

is exposed, however, the sawyer has already made a decision on log orientation that cannot be reversed in light of additional information obtained during the sawing process.

Researchers have investigated technology for possible applications in detecting internal defects in sawlogs. A technique known as computed tomography (CT) has become well known in medical imaging (33). Since commercial introduction just 17 years ago, CT has become the accepted method for obtaining three-dimensional internal information on patients and is used in every major medical hospital within the United States (14). Industrial CT scanning techniques have been described, and a variety of materials such as concrete, metal, plastic, and wood have been successfully scanned (3,4,8,11,13,18,19,21,28,29,45,46,49). Systematic methods for the evaluation of CT images from logs have also been described (13,18,27). In addition to developments in CT scanning, nuclear magnetic resonance (NMR) can also detect defects and moisture gradients in wood (10,15,34,50). However, these machines must be adapted for log scanning at production speeds, and software must be developed to delineate scanned defects and to determine best log

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Forest Prod. J. 41(4):25-30.



Paint Lines Define Grading Faces

Figure 1. — Illustrated are axis lines painted onto a log surface. The paint lines divide the log into four grading faces.

position to maximize lumber value yield. An industrial machine for detecting and locating internal defects could be developed if significant economic benefits from use of such information can be demonstrated (17).

The relative merits of different circumferential log orientations and sawing methods have been the topic of much research (2,5,6,9,12,23,30,32,37,38,41,44,48). A mathematical algorithm by Richards et al. generated a simulation of typical red oak knots in 62 conical logs (42). These logs were live, cant, and grade sawn by computer simulation at 12 rotational positions. The best position yielded 11 percent higher value lumber than the worst position. Other studies have located actual defects. Peter photographed 1-inch (2.54-cm) boards sawn from yellow-poplar logs and plotted knot locations within cylindrical logs (36). He manually simulated sawing by manipulating transparent overlays. From the simulated live sawing of 50 logs at 2 orientations, he found a 9 percent improvement at the best orientation compared to the worst orientation. Tsolakides used computer simulation with plotted log defects as data to test the influence of four rotational log positions and three sawing methods on lumber value yield from six red oak logs (47). Four points described log shape at each cross section, and defects were recorded to the nearest 1/4 inch (0.635 cm) in cross section and to the nearest 1 inch (2.54 cm) along the length of the logs. The computerized logs were assumed to be perfect cylinders. He obtained a 21 percent increase in lumber value of best over worst for the four rotations and three sawing methods. Since previous studies were conducted, advances in computer technology have made practical the collection and the processing of large amounts of data. Past simplifications, such as artificial defect generation and the use of cylinders to represent logs, are no longer needed. Therefore, a precise methodology for data collection, data handling, simulated sawing, and data analysis has been developed to examine possible improvements in lumber value due to knowledge of interior-log defects.

#### Log defect location methodology

Study logs are divided into four grade faces that later define a Cartesian coordinate system (Fig. 1). Each face is graded by the USDA Forest Service standard grades for factory lumber logs (22). In the coordinate system, the cross sections of the logs are in the x-y plane. The

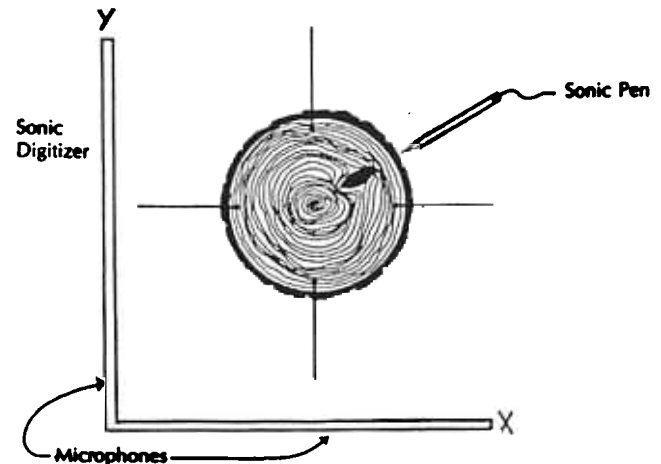


Figure 2. — Each log cross-sectional disk is placed on a sonic digitizer for data collection. A stylus is used to trace the periphery of each disk and the periphery of lumber grade defects found on each disk.

z axis connects the geometric center of each end of the logs. Lines are painted on the rough bark surfaces.

Study logs are physically crosscut into 2-foot sections, and each section is placed upon the bed of a bandsaw where 1/4-inch (0.635-cm) disks (including kerf) are cut transversely. Each disk is marked to designate the log and disk number (z coordinate). A 12-foot-long (3.65-m-long) log would yield 576 cross-sectional disks. This log crosscutting and coordinate-marking system follows procedures described by Tsolakides (47) and by Wagner and Taylor (48), except that 1/4-inch (0.634-cm) rather than 1-inch (2.54-cm) disks are cut. Other researchers have sawn 1-inch boards from logs and collected data from these boards (36,37,39,40).

The next step is the conversion of each disk into a computer-ready digital format. Log periphery and defect data are collected, cataloged, and transferred to ASCII computer data files with a sonic digitizer. Each log disk is placed on a 5- by 6-foot (1.54- by 1.83-m) panel containing the L-frame microphone of the digitizer (Fig. 2). The x-y axis marks on the disks, which were paint lines originally designating the four grading faces (Fig. 1), are aligned with the axis marks on the panel. The disk number (z) coordinate is entered through the computer's keyboard. A stylus traces the periphery of every eighth log disk and the periphery of lumber grade defects found on each disk. The sonic digitizer is interfaced to a microcomputer, and all collected data are stored on the computer's fixed disk and diskettes. Defect types are standard defects described by the National Hardwood Lumber Association (NHLA) Rules (31). Figures 3 and 4 show CAD/CAM graphic representations of the raw data collected from a test log. Figure 3 shows a reduced data set for the whole log, and Figure 4 shows a complete data set for a 2-foot (0.610-m) section of the log. The figures show the precise nature of the data with the log surface and internal defects shown in detail. Almost 55 thousand digitized points were collected to describe the whole log.

Raw data are prepared for simulation by correcting errors in the data, replacing defect descriptions with numeric designations, assigning numeric attributes to points inside the defect perimeters, associating similar defects in adjacent disks, and smoothing any erratic behavior of the data. This data preparation is carried out by a computer program specifically developed for this task. Data errors may include missing data and mislabeled defects. Each defect on each log disk (existing as a set of digitized coordinate points) is assigned a numeric attribute. The points, each 1/4-inch (0.635-cm) square, within a defect are found and assigned the same attribute as the points on the defect perimeter. When a defect overlaps another defect in an adjacent disk, the attribute associated with that defect is changed to that of the overlapping defect in the direction of the small-end of the log.

Due to the possible misplacement of axes on the surface of study logs, the disks may be incorrectly located on the digitizing panel. Such errors cause the disks to be improperly oriented with respect to one another. To correct these errors in the raw data, least-squares fourth-order polynomial regressions of the pith x coordinate on the z coordinate and of the pith y

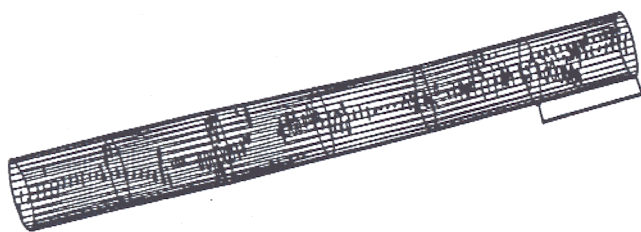


Figure 3. — Shown is a CAD/CAM graphics representation of a reduced data set for a test log. The log shape and defects within the log can be seen. The bracketed 2-foot (0.610-m) section is shown in more detail in Figure 4.

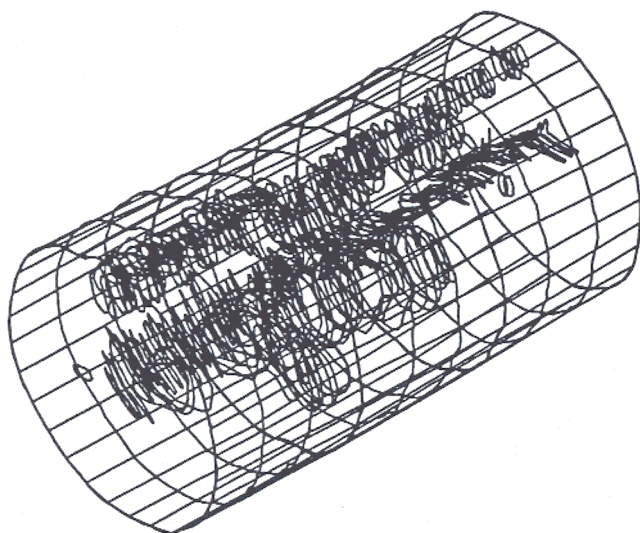


Figure 4. — Shown is a CAD/CAM graphics representation of the complete data set for a 2-foot (0.610-m) section of the test log. This figure shows the precise nature of the data. The log surface and internal defects are shown in great detail.

coordinate on the z coordinate are performed. All points with the same z coordinate (data collected from the same log disk) are translated so that the pith of that disk falls on both regression curves.

A processed-data file is created that contains the coordinates of each defect point within the log. An attribute characterizes the defect type of each point and distinguishes it from non-adjacent defects of the same type. Processed log data are assembled into a three-dimensional array (Fig. 5) and are computer sawn by a simulation program. The log array size is 101 × 101 × 576 1/4-inch (0.63-cm) increments.

### Simulated log sawing methodology

Methodologies for three simulated sawing procedures were developed: sawyer grade sawing, tomographic grade sawing, and live sawing. In simulated sawyer grade sawing, the program positions the log based upon grade faces selected during grading (Fig. 1). The computerized log is rotated 45 degrees so that grade faces may be sawn squarely with vertical or horizontal sawlines. Specifically, one board is sawn from the face with the poorest grade. In the case of two poor grades, the poorest face with best opposite face is cut first. Then the best face is cut until a board is produced with a grade lower than the expected lumber grade of the second-best log face. Boards are then cut from the second-best face until an adjacent face promises a better grade board. This method has been described by Malcom (26). Prior to sawing, the log is first tilted downward by rotating about the lowest point of the large end of the log. This procedure places the log in a position as it lays on a headrig carriage. Additionally, to effect full taper sawing, the log is offset toward the best face. In this way, log taper is sawn from the poor face, and more full-length boards are removed from the best face. Before sawing the second-best face, the log is offset toward that face.

As a variation on the sawyer grade sawing procedure, a tomographic grade sawing procedure was also developed. This method evaluates internal log-scan data for selecting initial log orientation and log turning sequence. Specifically, the procedure temporarily reduces the log to the largest square cant that has faces with edges containing no more than 50 percent of the length in wane. The cant faces are then graded, and

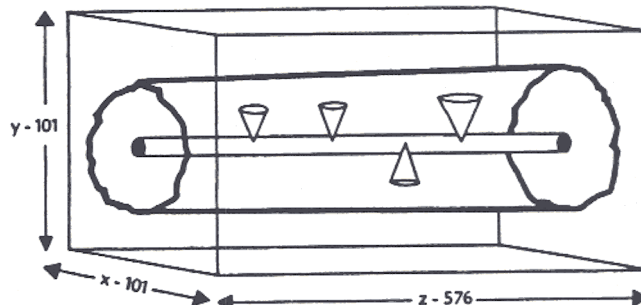


Figure 5. — Processed log data are assembled into a three-dimensional array for computer sawing. The log array is 101 × 101 × 576 1/4-inch (0.63 cm) increments.



TABLE 1. — Grades and prices for flat-sawn red oak lumber.<sup>a</sup>

Grade	Price
FAS	
SELECT	
1C	
2C	
3A	
3B	

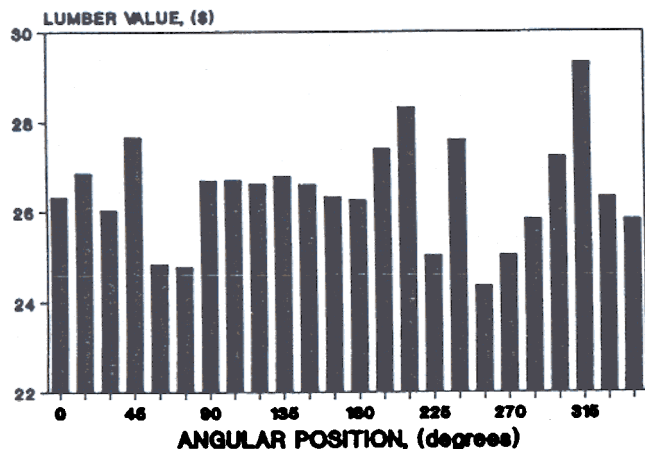
<sup>a</sup> Hardwood Market Report (16).

Figure 6. — The value of lumber sawn from the test log varied with circumferential orientation for the live sawing method. The maximum value was \$29.30 (\$US) and was 10.8 percent higher than the average value for all orientations.

these grades are used for log turning decisions, as were the log face grades for sawyer grade sawing. The log is then reassembled for simulated sawing. The tomographic grade sawing method is performed at multiple orientations. This method has been called "decision sawing" in previous research (41).

Hardwood logs of low grade or small diameter may be sawn by the live sawing full-taper method to improve lumber-value yield (20). Therefore, a live sawing full-taper procedure was developed to evaluate the impact of internal log-scan data on the value of lumber produced by live sawing. By this method, the log is offset toward the opening face. Boards are then sawn from this face until the entire log is processed with no additional turning of the log. Although this procedure differs from the industrial practice of sawing the log to the center, rotating the log 180 degrees, and sawing to the center dog-board, the resulting lumber is the same.

The initial log orientations of study logs are the orientation as digitized. Subsequent orientations are obtained by rotating the log in multiples of 15 degrees. For live sawing, logs are rotated through 345 degrees. For tomographic grade sawing, logs are rotated through 75 degrees. Because sawlines are placed parallel or perpendicular to the orientation of the initial sawline, 75 degrees of rotation in the tomographic grade sawing procedure exhausts all possible lumber value variations for 15-degree incremental-rotations.

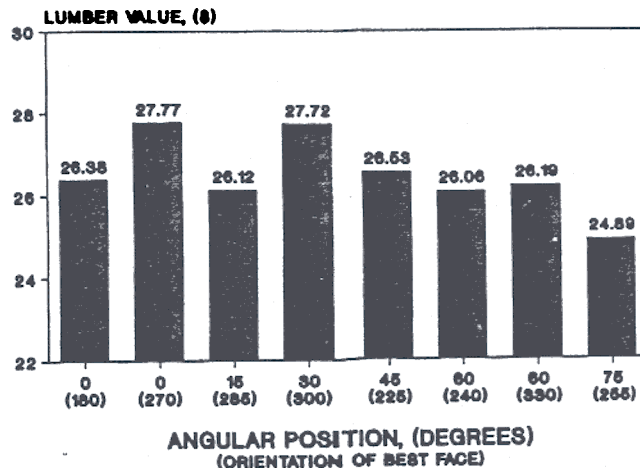


Figure 7. — The value of lumber sawn from the test log varied with circumferential orientation for the tomographic grade sawing method. The maximum value was \$27.77 (\$US) and was 5.0 percent higher than the average value for all orientations.

All lumber generated through simulated sawing is edged so that the board edges contain no more than 50 percent wane along their length. This wane limitation is described in the NHLA rules for FAS lumber (31). For lower grades of lumber (Selects, No.1 Common, No.2 Common, 3A, and 3B), wane above this limit is generally considered to violate the definition of a "well manufactured" board. These wane limitations agree with assumptions in past research (2,41-43).

Edged lumber is graded in accordance with NHLA rules by a computer program developed by Klinkhachorn et al. (24,25). Lumber is assigned a value corresponding to the grade and volume of each piece.

#### Verification of methodology

A southern red oak log, obtained in northeast Mississippi, provided data for verification of the experimental methodology. The log was relatively straight with approximately a 15-inch (38.1-cm) small-end diameter and 12 feet (3.66 m) long. Prices used to assign value to the lumber sawn from the log are shown in Table 1.

Figure 6 shows the value of lumber sawn from the test log by live sawing at each of 24 circumferential orientations. The maximum value of \$29.30 (\$US), occurred at 315 degrees. The maximum lumber value was 10.8 percent higher than the average value of lumber at all orientations, \$26.45 (\$US), with a volume increase of 3.2 percent above the average. The maximum volume yield occurred at the 330-degree orientation, where 5.4 percent more lumber than average was sawn. The value of this lumber, however, was 0.5 percent below average. Value improvement was largely the result of better grade yield rather than better volume yield.

Figure 7 shows the value of lumber sawn from the log by tomographic grade sawing at each of the eight circumferential orientations. The maximum value was

obtained at an orientation of 270 degrees from the best grade face. The maximum value yield for the tomographic grade sawing method, \$27.77 (\$US), was 5.0 percent above the average, with a volume yield 2.1 percent below average. Again, improved lumber grade, not improved lumber volume, resulted in the higher lumber value.

Since all faces of the test log had the same grade of F2 (22), two adjacent faces were picked as the best faces for two sawyer grade sawing turning sequences. Because the objective was to simulate the sawyer grade sawing methods and because both turning sequences were likely to be performed, an average of the results from the two sawings were compared with other methods. The average value and average volume of lumber from the sawyer grade sawing method was \$27.37 (\$US) and 139 board feet, respectively.

To compare the improved lumber value produced from the study log through internal log-defect information to that which could be sawn at a typical hardwood sawmill, the best live sawing value and the best tomographic grade sawing value were compared to the sawyer grade sawing value. The best live sawing value was 7.05 percent higher than the sawyer grade sawing value and produced 2.16 percent more lumber. The best tomographic sawing value was 1.46 percent higher than the sawyer grade sawing value, with 4.31 percent less lumber. Thus, the best live sawing and tomographic sawing values outperformed the sawyer grade sawing value through better grade yield.

### Summary and conclusions

A precise research methodology by which internal log-defect locations may select log orientation and sawing procedure to improve lumber-value yield was described. Procedures for data collection, data handling, simulated sawing, and data analysis were also described. A single test log verified the methodology. Results from this log showed significant differences in lumber value sawn due to circumferential orientation and sawing method. Live sawing and tomographic grade sawing outperformed sawyer grade sawing by 7.05 and 1.46 percent, respectively. Observations indicate that the research methodology performs as intended.

In the future, this methodology will be used to determine the improvement in lumber value that can be expected if logs are scanned for internal defects and if this information is used to select log orientation and sawing procedures. Obviously, data from additional logs will have to be collected and analyzed to draw meaningful conclusions about expected improvements.

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